

**THE CROTHERS ROAD LANDSLIDE COMPLEX**

**for:**

**The City of San Jose  
Office of the City Attorney  
151 West Mission Street  
San Jose, California 94510**

**by:**

**Norfleet Consultants,  
  
Norfleet Consultants Project Number 001443**

**February 28, 2001**

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February 28, 2001

Mr. M. Churchill  
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NC Proj. No. 001443

RE: Review of the Crothers Road  
Landslide Complex  
San Jose, CA

Dear Mr. Churchill

At your request, we have completed our review of the nature and the cause of the Crothers Road Landslide Complex.

In early February, 1998, a large landslide occurred along the south side of the valley at the west end of Alum Rock Park (Figures 1, 2, and 3). The landslide is roughly 500 feet long and 200 feet wide and has displaced approximately 175,000 cubic yards of soil.

The landslide occurred on lands owned by the City of San Jose, Santa Clara County, and private landowners. The landslide shifted part of Highland Drive, offset Crothers Road, offset a park maintenance road, and offset Alum Rock Avenue. The landslide also damaged a house at 16219 Highland Drive (Goode property), damaged a driveway at 16196 Highland Drive (Azevedo property), and forced the rerouting of several underground utility lines. The affected sections of Highland Drive and Crothers Road were quickly closed.

The Crothers Road Landslide Complex has been referred to as the Alum Rock Landslide, the Highland Landslide, the Alum Rock Park Landslide, and the Crothers Landslide. It will be referred to as the Crothers Road Landslide Complex in this report.

The scope of our evaluation included:

- observations of the landslide between March, 1999 and December, 2000;
- review of geologic studies and maps of the area;
- review of engineering studies of the landslide;
- review of legal documents related to the landslide;

- creation of a detailed topographic survey of the landslide and adjacent area; and
- preparation of this summary report of findings.

## **Landslide History**

### *Goode Property*

The property at 16219 Highland Drive (Figure 3) has had several owners over the past twenty years (Leonard, Fulford, Goode, and the current owner). It will be referred to as the Goode property in this report. The property consists of two lots. The driveway entrance is on Alum Rock Avenue (No. 16213), while the mail box is on Highland Drive (No. 16219). The house was built circa 1949. A boundary survey in 1999 indicated that the east end of the Goode property where a storage shed is located is actually on County property (Figure 14, location W). This area will be referred to as part of the Goode property in this report.

In November 1983, the Goode property was observed as part of an insurance evaluation (Merrill, 1983). Earlier that summer (July, 1983), a water main broke and flowed for about two hours. The break was apparently located on a slope just north of Highland Drive (Figure 4 and 14, location F). Water from that break eroded soil along the east side of the Goode property and washed out a section of a cut slope on the south side of Crothers Road (Figure 5). The owner of the property at the time, Mr. Leonard, thought that the water leak caused an increase in the settlement of his house and filed an insurance claim. During discussions with the engineer, the owner indicated that there had been slow settlement of the north side of the house since 1970, and the settlement rate significantly increased in 1981-82 and in 1983. The engineer's opinion was that settlement of soils along Highland Drive caused the water line to break, but it was unlikely that the leak caused or contributed to the distress to the house.

During 1985-86, the house foundation was upgraded. As part of that work, the garage slab and other concrete slabs were removed and replaced, new footings were constructed, and ≈10 foot deep, concrete underpinning piers were installed beneath the downhill (northern) part of the house. A retaining wall adjacent to the garage was replaced. It is not known if the house floors were leveled.

In 1988, the house was sold to Mr. Fulford. As part of the property evaluation, a floor level survey of the southern half of the main floor of the house was performed by Westfall Engineers, Inc., on September 8, 1988. That survey indicated that the southern end of the house was 2 to 3 inches out of level. Westfall Engineers performed another floor level survey on July 11, 1991. That survey data was not available, but a discussion of the data indicated that there had been additional settlement between 1988 and 1991. Westfall Engineers believed that the movement was the result of settlement or slippage of the underlying soils. The house was then sold to Mr. Goode.

In late January, 1998, Mr. Goode noticed cracks and ground shifting at the east end of his property. Over the next week or so, the shed in his rear yard shifted north and dropped. At the same time, he noticed cracking and shifting in the interior and exterior of his house. He filed an insurance claim about the house damages circa February 7, 1998. Over the next few weeks, the rear shed shifted several feet (Figures 6 and 7), exterior brick walkways cracked and shifted, the driveway cracked and pulled away from the garage slab, and additional cracks occurred in the

interior of his house. In his deposition, Mr. Goode indicated that he believed that a large water main near Highland Drive broke and flooded his rear yard in late January, prior to significant movement of his house. San Jose Water Company records indicated that they were first notified of the water main break on February 14, 1998. It is unlikely that a break of this magnitude would go unreported for more than a day. We discounted Mr. Goode's opinion of the date of the water main break for this reason.

In July, 1998, the house was evaluated by Hallenbeck & Associates as part of the insurance claim evaluation. A floor level survey done at that time indicated that there was an elevation difference of 5.2 inches across the house (south to north). It was Hallenbeck's opinion that a subsidiary slide of the main landslide damaged the northern part of the house.

With the permission of Mr. Goode, we briefly observed the house on December 31, 2000. We observed that the rear entrance door was noticeably racked (Figure 8), with the north side of the frame having shifted and pulled apart one to two inches. There were floor and ceiling cracks in the rear hallway (Figure 9; adjacent to the door shown in Figure 8), in the kitchen, and in the store room. Most of that distress had been patched circa 1998. Shifting continued between the initial movement in 1998 and the present, causing additional cracking. That distress had also been patched.

There was scattered distress to the brick walkways, stairs, and short walls in the rear yard. Adjacent to the house, one to two inch wide cracks had developed in the brick walkway and the short brick wall (Figure 10). The brick wall had been offset several inches. Some the distress was recent (within the past year), some occurred as a result of the 1998 landslide event, and some likely developed during the 1983-84 landslide event. The older cracks had been patched, and new cracks had developed in the same location. The new cracks were up to 1/2 inch wide. There were cracks in the lower part of the brick stairs leading to the Highland Road entrance. The brick walkway surrounding the hot tub (built in 1996) had noticeably deformed and dropped (Figures 11 and 12). It is unclear if this was related to landslide movement. There was a series of arcuate, east-west trending cracks in the driveway adjacent to the garage (Figures 13 and 14, location A), and the driveway had dropped several inches with respect to the garage floor slab (Figure 15). The west end of that zone was in line with a zone of deformation on Crothers Road (Figure 14, location C).

### *Utility Lines*

There are water mains beneath Highland Drive (the Highland Drive Loop), Alum Rock Avenue, and Crothers Road. The mains are owned and maintained by the San Jose Water Company. All are fed by the same water tank. The Highland Drive main was installed circa 1930 and has not been replaced. That main is a 6 inch in diameter, cast iron line with rubber O-rings. It has a working pressure of 60 to 70 pounds per square inch (psi). A portion of the line was damaged by the 1998 landslide. The damaged section was eventually abandoned in late 1998.

The water main beneath Alum Rock Avenue supplies water to Alum Rock Park and is the sole source of water for the Park. The San Jose Water Company section of the main was installed in 1928 and is a 6 inch in diameter, cast iron line with O-rings. It has a slightly higher operating pressure because it is lower in elevation. The San Jose Water Company maintains the main up to the Park boundary (approximately at the crest of Alum Rock Avenue). The main within the Park is maintained by the City of San Jose. A section of the line was damaged by the 1998 landslide.

The damaged section was replaced with an above ground line along the south side of Alum Rock Avenue. This allows continuous visual observations of the line for water leaks.

In the late 1970's, the San Jose Water Company was requested to provide additional water pressure and flow control for fire fighting in this area. In response to this request, they constructed a water main circa 1979 that connected the Highland Drive main and the Alum Rock main. It extended beneath the south side of Crothers Road, and consisted of a 6 inch in diameter, ductile iron water pipe. A section of the line below Highland Drive was replaced in 1987. The line was extensively damaged by landslide movement in 1998 and was abandoned. We will refer to this main as the Crothers Road main.

There are sewer lines beneath Crothers Road and Highland Drive. The line beneath Crothers Road is owned and maintained by the City of San Jose. The line was installed in the mid 1970's when the Peacock Gap development was built. The line originally was a 6 inch in diameter vitrified clay pipe, that appears to have been located beneath the outside edge of Crothers Road (it was struck by boring 4-A in 1998). A section of the line was badly damaged by landslide movement in 1998 and was temporarily rerouted in an above ground line that extended along the Maintenance Road. The temporary line was permanently replaced in 1999. The new line extends beneath the Maintenance Road and consists of 6 inch in diameter, high density plastic pipe with flexible joints. The line beneath Highland Drive is owned and maintained by Santa Clara County. Little is known about that line. It is likely that the original line consisted of 6 to 8 inch diameter vitrified clay pipe. We do not know if the line has been replaced/repared.

There was a PG&E gas line beneath Crothers Road. It was initially damaged by a small landslide in January, 1998. The line has been rerouted, but we do not know the location of the new line. There are underground telephone lines at the west end of Crothers Road. They were rerouted during the summer of 2000.

### *Crothers Road*

Crothers Road is quite old, having been in existence prior to 1930. Little is known about its pre-1983 repair history. When the Crothers Road main was installed in 1979, the west end of Crothers Road was slightly widened and a drainage ditch was constructed along the south side of the road. This work created a 2 to 3 foot high cut slope along the south side of the road below the Goode property.

In July 1983, the Crothers Road main broke just downhill of Highland Drive, allowing water to flow for several hours. Water from this break flowed downhill across the east end of the Goode property and eroded the southern bank of Crothers Road (Figure 5). The break was repaired, and the main was put back into service. There is no indication that active landslide movement was recognized at that time. Several photographs were taken in November, 1983, of the west end of Crothers Road by a geologist from the firm of Merrill and Seeley as part of their evaluation of the Goode property for Farmers Insurance Company (Figures 16 and 17). Figure 16 shows a road patch that extends diagonally across Crothers Road at approximately the same location as the main scarp that developed in 1998 (Figure 14, location B). There is no record of any utility line in the location of the patch. This suggests that the patch was placed to cover cracking/offset in the road. A berm is visible along the outside (north) edge of Crothers Road. During our field work, we located this berm. It is 28 to 32 inches wide, 4 to 6 inches high and was several hundred feet long. A patched zone along the inside (southern) edge of Crothers Road (Figure 16)

likely indicates the location of the water main. The berm kept surface waters on the road surface. Figure 17 shows diagonal cracks in the middle of Crothers Road at approximately the same location as the scarp that developed in 1998 (Figure 18 and Figure 14, location C). These photographs suggest that there was movement of the landslide complex in 1983.

In 1987, the repaired section of this main was replaced (apparently because the line had again separated below Highland Drive). This work suggests that there was sufficient ground movement in the Crothers Road area during the early part of 1987 to pull the water main apart. At the same time, it is believed that the San Jose Water Company constructed a rip-rap sack wall (Figure 19 and 14, location D) along the southern (uphill) side of Crothers Road in the vicinity of the eroded bank that occurred as a result of the 1983 water main leak. It appears that the west end of Crothers Road was resurfaced at this time.

In November, 1997, the city of San Jose retained Soil Engineering Construction to repair a small landslide (slip out) that occurred in the spring of 1997, east of the Crothers Road Landslide Complex (Figure 14, location E; plans dated October 27, 1997, by Soil Engineering Construction). Soil Engineering field notes indicate that this was a small slip out adjacent to Crothers road that extended to the edge of the road pavement. There was no indication that the slip out damaged the road surface or extended beneath the road surface. To stabilize the slip out, a soldier pile wall was constructed across the slip out. The concrete piles extended 10 feet deep outside of the slip out (end piles) and 14 feet deep inside the slip out. An evaluation of the plans suggests that the repair design assumed that failure surface was located near or at the top of concrete piers. Subdrains were installed behind the wall (shown on plans and observed in field). Discussions with City staff who observed this site at the time indicate that there were no obvious indications of distress to Crothers Road at that time.

In early February, 1998, (circa 2/6/98) this area failed again (Figure 20). The new failure was larger. It extended partially across Crothers Road and destroyed the soldier pile wall that had been built to stabilize the previous failure. The failure damaged gas and sewer lines beneath the north side of Crothers Road. Soil Engineering Construction was contacted, and they observed the failure between February 7 and 9, 1998. The area surrounding the headscarp was barricaded, and utilities (including the sewer line) that crossed the failure were rerouted. This failure restricted traffic on Crothers Road but did not cause the road to be closed. This failure occurred as a single event and has not noticeably changed since it occurred in 1998. In their report, Earth Tech indicated that although this failure "appears to be a separate localized slump, it was very likely affected by the main slide" (Earth Tech, 1999, p. 4). City staff who observed the slip out in early February, 1998, indicated that they observed indications of distress to Crothers Road adjacent to this area at this time (i.e., cracking on the road surface), but they did not understand the implications or the magnitude of the distress at that time.

### *Crothers Road Landslide Complex*

There was continuous rain during January, 1998, and a major storm passed through the area in the first week of February, 1998. This storm triggered numerous new landslides and reactivated old landslides throughout the Bay Area. The large Fremont landslide also occurred at this time. Alum Rock Park was closed because of flood and landslide damage to Park facilities.

Indications of earth movement began to appear in the Crothers Road-Highland Drive area in mid January, 1998. Ground shifting and house distress prompted Mr. Goode to file an insurance claim on February 7, 1998.

On February 14, 1998, a water main break in the Crothers Road main was reported to the San Jose Water Company. The break was just north of the edge of Highland Drive. It was reported that the pipe pulled apart at a joint (there was no physical damage to the pipe itself). The water flowed downhill to Crothers Road, eroding gullies on the Goode property. It is not known exactly how long water flowed from the broken main, but it appears that it was shut off within a few hours. The water main is gravity fed from a large, nearby water reservoir. Water levels in the reservoir are automatically maintained by a pump. Water levels in the tank are coarsely measured by a float. There is no water meter on the outlet lines. San Jose Water Company reviewed the water level measurements during early February, 1998, and reported that there were no out of the ordinary water level variations during that time period. However, only very large water main leaks could affect water levels in the tank.

It appears that the 1998 water main break and resulting damage occurred in the same locations as the 1983 water main break (and the possible 1987 water main break). The ground continued to move. Within a few days, fault scarps on Highland Drive increased in size by several feet, and widespread cracking and ground deformation occurred on Crothers Road and Alum Rock Avenue.

On February 17, 1998, the broken section of the main was replaced with a slip joint that could accommodate up to 2 feet of movement. As part of this repair, the Water Company placed class II base rock in the repair zone (a 20 by 40 foot area) below Highland Drive, and covered the area with plastic. The line was repressurized, but other breaks were discovered in the section of the main beneath Crothers Road. The magnitude of distress to this main caused it to be abandoned a few days after repairs began. In late February/early March, shear breaks began to occur in the Highland Drive water main on either side of the Crothers Road Landslide Complex headscarp. The location and nature of these breaks caused the Water Company to cut off and abandon a 350 foot long section of the Highland Drive water main that extended across the Crothers Road Landslide Complex. Two inch in diameter high density polyethylene lines were laid across the damaged area to provide water service to the properties that had been served by the damaged main.

The landslide continued to creep until about May, 1998, when movement appeared to noticeably slow down. Santa Clara County applied to FEMA for funds to evaluate/repair the landslide. On April 9, 1998, the area was inspected by FEMA representatives, who prepared a Damage Survey Report (DSR, number 73943). That report stated *"heavy El Nino rains have saturated this hillside resulting in a major hillside slip which poses an immediate threat to public health and improved property and utilities ... an immediate geotechnical study is required to make recommendations for temporary protective measures to attempt to slow and possibly stop hillside movement and prevent further damage."* FEMA denied funding to repair the landslide because they believed that the current landslide was a long-standing, ancient natural landslide.

On April 23, 1998, Santa Clara County Surveyors installed 53 survey control points along Highland Drive and Crothers Road to monitor movement of the upper part of the landslide complex (Figure 44). The control points were resurveyed several times in 1999 and 2000. Control point displacement between April, 1998 and February, 2000, is listed in Table 1 (at end



of text). At the same time, the surveyors surveyed three north-south trending topographic profiles along the body of the landslide complex from Highland Drive to Penitencia Creek and prepared a base map of the uphill portion of the landslide complex (Highland Drive - Crothers Road area).

Soon after large-scale movement occurred in mid-February, 1998, Highland Drive and Crothers Road were closed. Alum Rock Avenue and Alum Rock Park had been closed a few weeks earlier because of storm damage to the park. The park was repaired, and damaged sections of Alum Rock Avenue were patched (Figures 21 and 22) and the road and park were reopened the week of June 22, 1998. Smaller scale movement continued to occur (Figure 23). Alum Rock Avenue was repaved in mid March, 1999, and again in April, 2000. Sand bags were placed along the outside edge of Alum Rock Avenue in late 1999 and again in 2000 (Figure 26).

Figures 22, 24, 25, and 26 illustrate shifting of Alum Rock Avenue between the spring of 1998 and February, 2001. Figure 27 was taken in the middle of the east bound lane just west of the landslide in February, 2001. Our measurements indicate that the west end of Alum Rock Avenue has shifted 8 to 9 feet horizontally and a minimum of 3 to 4 feet vertically since February, 1998. These measurements are coarse because the original edge of the road is covered with several feet of asphalt. Figures 28, 29, and 30 illustrate shifting of the Maintenance Road between March, 1999, March 2000, and February 2001. This shifting is not as obvious because gravel was placed on the Maintenance Road in mid-1999 to allow continued use of the road by Park personnel. Figures 31 and 32 show changes in Crothers Road between March, 1999 and March, 2000. Again, the shifting is not as obvious because Santa Clara County placed several feet of fill over the fault scarp in the summers of 1999 and 2000 for equipment access. Our measurements indicate that the west end of Alum Rock Avenue has shifted 6 to 7 feet horizontally and 5 to 6 feet vertically since February, 1998. Figures 33 and 34 illustrate the nature of the headscarp along Highland Drive.

## Landslide Evaluation

### USGS

A preliminary photo interpretation map of landslides in the study area was done by Nilsen (1972; at a scale of 1:62,500). This map was one of series that covered the entire Bay Area. A landslide is shown on the map at the location of the Crothers Road Landslide Complex (Figure 35). The symbol used on the map for this landslide indicates that this landslide was "200-500 feet in longest dimension." After his 1972 maps were released, Dr. Nilsen received many requests from geologists and engineers to release his working maps (done at a scale of 1:24,000; Nilsen, personal communication, 2000). This was done in 1975 (Nilsen, 1975). The 1975 published map is a redraft of his working map, but the Crothers Road Landslide Complex is not shown on that map (Figure 36). It appears that there was a transcription error. The 1975 map contains the notice: *"this map is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature."* The 1972 map did not contain this notice.

In 1974, Wright and Nilsen released a relative landslide abundance map in the Bay Area (Wright and Nilsen, 1974). Using this map, one could estimate the percentage of the ground surface that would be covered with landslides. In the study area, the map indicated that between 20 and 30 percent of the ground surface in the vicinity of the study area is covered with landslides (Figure 37). The map also showed the location of the Crothers Road Landslide Complex.

Nilsen, et al. (1979) performed a regional landslide risk analysis of the greater Bay Area. They created slope stability maps that illustrated the relative susceptibility of the land surface to landsliding (Figure 38). Five zones were shown on the maps. The zones ranged from stable areas (Category 1), where landslides are highly unlikely to occur, to unstable areas (Category 5), where landsliding is very likely to occur. The maps were based on an analysis of three of the more important factors that contribute to and control the generation of landslides: the nature of the underlying bedrock, the slope of the land surface, and the presence or absence of earlier landslide deposits in the area. The study area was mapped as Unstable (Category 5), "areas that are underlain by or immediately adjacent to landslide deposits" (Figure 38).

### *Earth Tech*

In the summer of 1998, Earth Tech, Inc. (formerly Rust Environmental) was retained by Santa Clara County to evaluate the existing condition of the upper part of the landslide between Crothers Road and Highland Drive, and provide recommendations for emergency repairs (funding provided by FEMA). They did not evaluate the cause or nature of the landslide itself. The final report was issued in January, 1999. As part of their study, they reviewed historic aerial photographs, drilled 7 geotechnical borings (three of the borings became inclinometers and 4 became piezometers - the borings ranged from 60 to 70 feet deep), drew cross-sections, and prepared an initial landslide map of the area (Figures 39, 40, 41, and 42). It was their opinion that groundwater and the heavy El Nino rains were the major contributing factors in causing the landslide.

Their mapping indicated that instead of a single landslide, there was a landslide complex that contained several linked landslides (a composite landslide). The landslide complex was approximately 250 feet wide and 550 feet long, extending from Highland Drive to Penitencia Creek. They estimated the depth and orientation of potential landslide failure planes beneath the upper part of the landslide complex (Highland Drive-Alum Rock Avenue area), but did not provide any analysis for the lower part of the landslide complex (Alum Rock Avenue - Penitencia Creek area).

Earth Tech's geologic analysis indicated that the bedrock beneath the site "*consists entirely of fractured and crushed, interbedded shale, siltstone and sandstone of the Berryessa Formation. The upper portion of the bedrock, extending to depths ranging from 20 to 40 feet, is severely weathered and is typically highly oxidized. At depth, the bedrock becomes fresh to slightly weathered and is . . . generally unoxidized. In some cases, a transition zone of moderately weathered bedrock occurs between the severely weathered and fresh zones. The bedrock units are overlain by colluvium or slope debris and locally by fill (primarily road embankment fill).*" Possible failure zones were interpreted within severely weathered bedrock, and the basal slip surface was thought to be located at or near the base of severely weathered bedrock. It was also thought possible that deeper failure surfaces might exist within soft clay zones in moderately weathered bedrock.

Inclinometers were installed on Crothers Road and Alum Rock Avenue (Figure 43) during the week of June 24, 1998, with initial readings taken on July 8, 1998 (Table 2). These inclinometers indicated that discrete slide planes were located 35 to 55 feet below the ground surface. By February, 1999, the inclinometer casing in inclinometer I-2 had deflected to a level that the probe could not pass below a depth of 48 to 50 feet. Inclinometer I-1 had also deflected

a noticeable amount. Circa June, 1999, inclinometer I-3 and the upper parts of inclinometers I-1 and I-2 were converted into TDR units (Time Domain Reflectometry). The TDR cables were grouted within the accessible portions of those casings. Note: a probe is lowered down an inclinometer to monitor ground shifting while a TDR unit measures electrical changes in a coaxial cable to monitor subsurface ground shifting. At the same time, new inclinometers (I-4 and I-5) were installed adjacent to I-2 and I-1, respectively (18 to 22 feet west). The new inclinometers were deeper (98 feet). We do not know if those borings were logged by a geologist. By July, 1999, the new inclinometers indicated that the main slide body was moving 3/4 to 1 inch per month. They also indicated that there was movement (a deeper slide plane?) 75 to 80 feet below the ground surface (Figure 69). The TDR cables have not shown any deformation. This is thought to be a result of them being grouted within the inclinometer casing which makes the cable much less sensitive to ground movement. We do not know if the inclinometers are still monitored.

Table 2: Inclinometer information between June 1998 and October, 1999. Depths are in feet below the ground surface

Number	Depth	Zones of Movement
I-1	60 feet	35 feet and $\approx$ 55 feet
I-2	68 feet	50 feet and $\approx$ 65 feet
I-3	70 feet	$\approx$ 35 feet
I-4	98 feet	34, 55, and 75 feet
I-5	98 feet	35, 60, and 75 feet

Initial groundwater levels were measured in all borings when they were drilled (Table 3). Boring 4-A struck an abandoned sewer line approximately 4.5 feet below the ground surface and was abandoned. The rig was moved west to the location of piezometer P-4.

Table 3: Initial groundwater depths in the borings (in feet below the ground surface)

Boring	Water Depth
I-1	35
I-2	not recorded
I-3	not recorded
P-1	not recorded
P-2	not recorded
P-3	28
P-4	not recorded

Between June and August, 1998, four piezometers were installed around the edges of the landslide (Figure 43). No piezometers were installed within the landslide itself. The construction of all of them was similar. They are 40 to 42 feet deep, filled with sand between 25 and 40 feet, and have a grouted sanitary seal between 25 feet and the ground surface. The casing is a 2 inch diameter PVC pipe with slots between 30 and 40 feet.

Groundwater levels in mid 1998 and on March 3, 2001 are listed in Table 4. The 1998 water levels were taken from the Earth Tech report, and show that groundwater levels during the

summer of 1998 were dropping. We do not know if the piezometers were monitored after August, 1998. We measured the groundwater levels on March 3, 2001, after almost two weeks of rain. The top of piezometer P-2 had been covered with asphalt and could not be located. The well box for piezometer P-4 was missing its cast iron lid. At the bottom of the casing, we encountered several inches of water standing over a foot or more of muck.

Table 4: Groundwater depths in 1998 and in 2001 (depth in feet below top of casing).

Piezometer No.	6/30/98	7/1/98	7/28/98	8/10/98	3/1/01
P-1	20	22.3	21.8	22.5	27.3
P-2	NA	NA	dry	dry	NA
P-3	29.2	29.4	30.8	31.4	31.8
P-4	NA	29.8	33.3	34.3	37.2

Earth Tech recommended installation of horizontal drains (hydrodrains) below Alum Rock Avenue and along the maintenance road to reduce groundwater levels within and beneath the landslide complex. On July 9, 1999, Earth Tech provided hydrodrain installation specifications. FEMA (DSR 27295; August 26, 1998) authorized funds to install the hydrodrains, and they were installed fall 1999. The location of the hydrodrains is shown on Figure 45. We do not know their construction details. The drains reportedly flowed noticeable volumes of water when first installed. Since then, they have produced a relatively small but constant flow of water. We do not know if the piezometers were monitored after hydrodrain installation to determine the effectiveness of the hydrodrains. Figure 46 shows the combined outflow from the seven hydrodrains along the Maintenance Road on March, 15, 2000. Figure 47 shows the combined flow from the nine hydrodrains below Alum Rock Avenue at the same time period. Observations of this outlet on February 24, 2001 (after two weeks of rain) showed a similar volume of flow. We estimated the flow at 1/2 to 1 gallon per minute at that time. On March 3, 2001, we observed the flow from the individual hydrodrains. Along the Maintenance Road, there was no observable flow from hydrodrains 1, 2, 3, 4, and 5. There was a trickle from hydrodrain 6. Hydrodrain 7 flowed in the range of one gallon per 8 minutes. Below Alum Rock Avenue, there was no observable flow from hydrodrains 8, 12, 13, and 14. There was a trickle from hydrodrains 9 and 16. Hydrodrains 10 and 11 each flowed in the range of one gallon per 8 minutes.

The hydrodrains are routinely observed by Park maintenance personnel. In mid summer, 2000, the outlet pipes for all of the hydrodrains along the Maintenance Road were broken off by vandals. The damage was repaired within a few days. The maintenance personnel indicated that there is a noticeable variation in flow between hydrodrains (personal communication, September, 2000). They observed that hydrodrains 10 and 11 produced the majority of water for the hydrodrains below Alum Rock Avenue. This observation is consistent with our measurements made on March 3, 2001.

### *Kleinfelder*

Kleinfelder, Inc. was retained by the City of San Jose in 1999 to provide an engineering evaluation of feasible alternative methods for reconstruction of the damaged section of Alum Rock Avenue. An investigation or determination of the cause of the landslide was outside of their scope of work. The final report was issued on August 6, 2000.

Kleinfelder performed reconnaissance geologic mapping of the area, identified areas of new landslide movement, and documented changes in previously identified distress (Figure 49). That information was superimposed on Earth Tech's landslide base map. The Kleinfelder geologist recognized large-scale erosion of the toe of the landslide by Penitencia Creek and identified a two inch thick clay zone in that erosional zone that appeared to be part of the basal failure plane. The clay layer was sampled for geotechnical testing (strength properties were: angle of friction = 18 degrees, cohesion = 550 pounds per square foot [Torvane measurement]). Several months after their field mapping, we observed the location of that zone in the field with the Kleinfelder geologist and generally agreed with his identification and conclusion as to its significance (the actual exposure of the clay zone had been covered by subsequent slumping). We could not determine if the clay zone was in place or it had been shifted from its original location by subsequent landslide movement (allochthonous).

Kleinfelder evaluated several repair methods to stabilize Alum Rock Avenue where it passed over the landslide. These were: a) lowering the groundwater using horizontal drains and/or a deep drainage gallery near the top of the landslide; b) replacing the upper slide mass with a reinforced earth fill, and c) construction an A-Frame tied-back drilled pier wall located at mid-slope below Alum Rock Avenue. They also briefly analyzed construction of a buttress fill on the toe of the slope.

Based on their slope stability analyses, Kleinfelder found that lowering the groundwater using horizontal drains would not be sufficient in and of itself to stabilize the landslide. Deep drainage galleries might technically lower the groundwater table enough to stabilize the landslide; but they would be difficult to properly construct, and they could easily be destroyed by minor amounts of continued landslide movement. These problems led Kleinfelder to not recommend a pure drainage solution. They also considered mass grading of the upper part of the landslide complex. This entailed deep excavation and replacement of the landslide mass (to depths of 50 feet or more) across the full width of the landslide (varying between 150 to 250 feet wide). A numerical analysis of this repair method suggested that the lower (unreconstructed) section of the landslide would move several feet, but the reconstructed section would be stable. Heavy equipment access, the stockpiling of excavated material during construction, and removal of all trees and vegetation from the upper part of the landslide would present significant problems and would likely make this solution unacceptable. Their recommended solution was the construction of an A-frame, tied-back, drilled pier retaining wall just below Alum Rock Avenue. The piers would be large, approximately 4 feet in diameter and 90 to 110 feet long. The pier tops would be joined with a large, reinforced steel grade beam, and tie backs would connect the end piers into stable material outside of the landslide. Some large trees would have to be removed.

Both the slope reconstruction and the retaining wall would divide the landslide into two independent sections. The uphill section would be restrained while the downhill section would still be free to move. The preliminary analysis suggested that the upper part of the landslide would move several feet before it would stabilize. There was no analysis to determine if either solution would alter the movement patterns of the lower part of the landslide. They did not evaluate the effects of continued erosion of the toe of the landslide by Penitencia Creek. In all solutions, Kleinfelder assumed that groundwater levels would be kept a minimum of 20 feet below the ground surface through the use of subdrains.

For their slope stability analysis, they assumed that there was not significant ground movement below 50 feet depth (the landslide complex is a classic translational feature). Kleinfelder stated

*" The primary movement of the slide mass was observed between 3-, and 50-feet from the ground surface in inclinometers 1, 4, and 5. The movement at 74-feet was not detected until 2 months after inclinometer installation. At that time, the cumulative movement at 34-feet was 1.3 inches. Because of these reasons, as well as the fact that no movement has been recorded at the 74-foot depth on I-5, which is downslope from I-4 it is our opinion that there is not significant slide [movement] deeper than 50-feet below the ground surface at this site. In order to confirm this assumption, we recommend that continued monitoring using inclinometers be carried out near the location of the initial three inclinometers."*

Inclinometer data acquired in late October, 1999, acquired by Mr. J. Baker indicates that there was movement in inclinometers I-4 and I-5 at depths of approximately 75 feet below the ground surface (Figure 69). Deep displacements ( $\approx$ 75 feet below the ground surface) may have a serious implication. Currently, the landslide complex appears to be a classic translational feature that is 40 to 50 feet thick (its length is much greater than its thickness). The development of discrete failure surfaces at depths in the range of 75 feet below the ground surface at inclinometers I-4 and I-5 may suggest the possibility that the landslide complex may have a deeper-seated rotational component. Only a small volume of data suggests this possibility, but it should be evaluated. If true, this could have major cost and scale impacts on any repair scheme. It is also possible that the reported deep movement is an artifact of the inclinometers or, if such deep movement truly exists, it is unrelated to landslide movement. Identification of the depths of active failure surfaces is critical to a complete understanding of the landslide complex.

### *Norfleet Consultants*

Norfleet Consultants was retained by the City of San Jose in 1999 to evaluate the history of landsliding and determine the causes of the recent movement. As part of our study, we field mapped the area, reviewed historic rainfall data of the area, reviewed historic stream flow data, and reviewed previous technical studies/documents of the area. We began to review historic air photographs of the area, but found that they provided little detailed information because of the extensive tree cover. Based on this information, we revised the existing geologic maps and cross-sections and made a preliminary evaluation of the extent and nature of the landslide complex. We made a public presentation about our preliminary findings of the Crothers Road Landslide Complex on October 2, 2000. The illustrations used in that presentation were given to the City of San Jose, and they were posted on the City web site in October, 2000.

### *Field Mapping*

During the fall of 1999 and early spring of 2000, we performed reconnaissance field mapping of the entire landslide complex using Earth Tech's base map. We also drew several cross-sections (Figures 51 and 52). That evaluation identified several features that had not been previously recognized.

- The landslide complex consists of a lower active zone and an upper passive zone. Individual landslides within the complex move at different times and rates.
- Penitencia Creek actively erodes the toe of the landslide complex during high water flows, and is a contributing cause of landslide movement.
- The landslide complex is wider than previously thought.

- There is an old landslide complex west of the Crothers Road Landslide Complex. The 1998 movement of the Crothers Road Landslide Complex reactivated a section of the old landslide complex. It is possible that there was minor reactivation of other parts of the old landslide in 1998.
- The landslide complex is fundamentally a translational feature, but the basal fault zone is not planar. There is a deeper trough along the west side of the landslide that controls movement of the upper part of the landslide.

In the fall of 2000, the landslide complex and surrounding area were topographically surveyed by the Culver Group, a licensed land surveying firm. Setting up the surveying instruments on Eagle Rock (on the other side of the valley) and extending survey rods up through the forest canopy allowed the area to be surveyed in a timely manner. A geologist was in the field with the survey crew, identifying and marking landslide features for the survey.

The landslide complex consists of several individual landslide units (referred to as blocks in this report) that move at different times and rates (Figures 50 and 53). The lack of compressional features within the landslide indicate that this is a toe driven landslide. As the lower blocks slide downhill into Penitencia Creek, they remove support from the blocks above them. This destabilizes the upper blocks and causes them to move into the void left by the lower blocks. The blocks move at slightly different times, with the lower blocks moving first followed by the upper blocks. This is consistent with the changes in horizontal and vertical elevation of the Santa Clara County survey points between 1998 and 2000 (Table 1 and Figure 44). That data indicates that the vertical movement exceeds horizontal movement in the upper part of the slide while horizontal movement exceeds vertical movement in the middle part of the slide (Alum Rock Avenue).

A large landslide below Alum Rock Avenue (Figure 53) extends to Penitencia Creek and appears to be the primary active feature (called the active block). This landslide is triangular in shape and is approximately 230 feet long and varies from 30 to 150 feet wide. Internally, it can be divided into three zones (upper, middle, and lower; Figure 14, locations G, H, I). This landslide is quite active. There are numerous fallen trees within this landslide, with few of them being very large (i.e., old). There are many open tension cracks that are up to 75 feet long, a foot wide, and several feet deep. The seep zone noted by Earth Tech and Kleinfelder is located along the southwest side of this landslide (Figure 14, location I).

Penitencia Creek erodes the toe of this landslide during high water flows, helping to destabilize it. Currently, there is an approximately 30 foot high, 125 foot long actively eroding zone at the toe of this landslide (Figure 54 and 14, location J). Over the past two years, approximately 20 feet of the toe of this landslide has been removed by Penitencia Creek. The landslide has locally pushed the creek several feet to the north and created a local nick point in the creek. The water surface slope above the landslide is flatter than the water surface slope below the landslide. We did not directly observe the basal failure surface of the landslide, but it appears that the failure surface crops out near the lower water flow water level in the creek. Our estimation of the location of the basal failure surface is consistent with the failure surface described by Earth Tech. We did not observe active deformation of the creek bed that would suggest that the failure surface extends below the creek.

A similarly shaped zone adjacent to the active block (Figure 53) is referred to as the key block. The block is about 225 feet long and up to 150 feet wide. When it was first observed (fall 1999), it appeared to be relatively undeformed and acted as a restraining block to slow down/stop movement of the landslides above it. By the summer of 2000, the block had shifted downhill, and there was a series of well defined fault scarps around and inside of the block. The upper (southern) boundary fault is located a few feet downhill from the hydrodrains below the east end of Alum Rock Avenue (Figure 48). The hydrodrains are located on the uphill side of the fault, while the drain manifold is located on the downhill side of the fault. During the fall of 2000, movement of the key block dropped the manifold and caused several of the plastic drain pipes to separate/break (Figure 48).

At this time there appears to be a relatively homogenous block between Alum Rock Avenue and Highland Drive, the central block (Figure 53). This block is about 200 feet wide and 225 feet long. The headscarp of the central block cut the downhill (northern) side of Highland Drive creating 6 to 10 foot high vertical scarps. Continued landslide movement during 1999 and 2000 caused the west side bounding faults that cut Crothers Road and Alum Rock Avenue to link up into a single feature. The east side bounding faults have still not linked up into a single feature.

Since 1998, the west side of the central block has offset Crothers Road a total of approximately 5 feet horizontally and 6 feet vertically. Most of the offset occurred in 1998. The scarp was covered with fill by Santa Clara County in mid-1998 and in 1999 to allow equipment access. During the winter of 99-00, the fill was offset 12 to 15 inches (Figure 57).

The hydrodrains along the Maintenance Road were installed circa October, 1999 (Figure 55). They connected to a rigid PVC pipe that directed the collected water west to a drain at Alum Rock Avenue. The pipe was originally installed with a continuous west slope. Landslide movement since installation has caused the pipe to deflect 18 to 20 inches horizontally and 22 to 24 inches vertically (Figure 56) between October, 1999 and January, 2001. There are no apparent leaks from the pipe as a result of this deflection.

Alum Rock Avenue has been offset approximately 6 feet horizontally, and 3 feet vertically where the road passes over the west side of the landslide complex. The road has been offset approximately 4 feet horizontally and 2 feet vertically where it passes over the east side of the landslide complex. The east part of Crothers Road has been cut by a series of diagonal faults spread over a 50 to 80 foot wide zone (Figure 58). Each fault has only a few inches of horizontal and vertical movement, but the total displacement is in the range of several feet horizontally and vertically.

Based on the deformation patterns and Earth Tech's boring information, there appears to be a trough beneath the west side of the central block (Figures 51 and 53). This part of the block is deeper and moves downhill at a faster rate than other parts of this block and creates a void into which the other parts of this block slide into. As movement continues, it is likely that the central block will break up into smaller blocks. Information from the Earth Tech boreholes showed that bedrock in the trough area was more weathered than bedrock outside of this area (there was no moderately weathered bedrock in the trough zone). This suggests that the trough outlines an area of weaker bedrock or is a zone of preferential groundwater flow (that has caused greater bedrock weathering in the trough area). In the central block, inclinometer information indicates that a significant zone of movement occurs at the contact between severely weathered bedrock and



fresher/moderately weather bedrock. That movement zone is deeper in the trough area than in other areas of the central block (Figures 51 and 52).

There is a continuous zone of deformation on which the central, key and active blocks move. However, it is unlikely that there is a single basal fault plane. Instead, there are stacked fault zones (each being several inches thick). It is unlikely that all of the faults are active at any one time. The inclinometer data illustrates this phenomena quite well (Figure 69).

Beginning in late 1999, several small faults appeared on Crothers Road west of the central block (Figure 59 and Figure 14, locations C, K, and L). There is not much displacement on these faults (a few inches), but orientation of these faults indicates that the area west of the central block is beginning to slide northeast into the trough. These faults indicate that the overall landslide complex noticeably widened during the winter of 99-00. The westernmost of these faults (Figure 14, locations A and C) is in line with a zone of deformation in the Goode driveway (and road distress in this area was photographed in 1983, Figure 17).

Southwest (uphill) of the central block, there are several small faults on Highland Drive (Figures 60, 61 and 14, location M). There is distress to an adjacent concrete block wall (Figure 66) at 16199 Highland Drive (Figure 14, location N). These faults are in line with a fault in the Azevedo driveway (16196 Highland Drive; Figures 62, 63, and 14, location P) and with cracking in a concrete block wall adjacent to the driveway at 16199 Highland Drive (Figures 64, 65 and 14, location Q). There is only a few inches of displacement on these faults.

These individual zones of deformation outline a wide but amorphous area that we call the upper block (Figure 53). The development of these features suggests two possibilities. One, they outline an area (the upper block) that has shifted slightly towards the central block. This means that development and movement of this block are directly related to movement of the central, key, and active blocks and that the basal failure plane should occur at approximately the same depth at the failure planes for the other blocks. Second, the upper block is independent of the other blocks. Instead, it represents the upper boundary of a failure plane that extends below the active, key, and central blocks (schematically shown on Figure 52). The deeper shear zones identified in inclinometers 4 and 5 may represent the failure surface of the upper block. If true, then the active, key, and central blocks are being carried along on top of this deeper failure surface. We have not observed similar earth movement east or southeast of the landslide complex.

The key block area of the Crothers Road Landslide Complex is adjacent to an older landslide complex (Figure 53) that is about 225 feet long and 150 feet wide. Movement of the key block caused a section of the older landslide complex to reactivate and shift 5 to 10 feet down hill (Figure 14, location V). There is little indication that the older landslide complex itself has begun to move. However, during 2000, a small fault developed on Alum Rock Avenue about 125 feet west of the Crothers Road Landslide Complex (Figures 67 and 14, location R). It is unclear if this fault is related to movement of the Crothers Road Landslide Complex (i.e. part of the upper block) or if it represents minor reactivation of the older landslide complex.

Until recently, Alum Rock Avenue was the public entrance into Alum Rock Park. It was heavily used by cars, buses, and small trucks. Between the summer of 1998 and the summer of 2000 the road was actively maintained by the City of San Jose Department of Streets and Traffic. Repair activities primarily consisted of patching and repaving the road as needed. The rate and scale of

repairs was dependent on the rate and scale of distress that appeared in the road. Figures 24 and 25 illustrate the movement of Alum Rock Avenue between March, 1999, and March 2000. By the summer of 2000, more than 3 feet of asphalt had been placed on the road surface. During the spring and summer of 2000, the section of Alum Rock Avenue that extended across the landslide began to break up. Numerous tension cracks began to appear throughout the road surface. The cracks were up to 20 feet long, several inches wide, and up to 3 feet deep (Figure 68). Development of these cracks accelerated during the early summer of 2000. They would be patched, and would then reappear a few days later. They were large enough that an entire bicycle wheel could easily fall into them. The development of these cracks was very unusual because the deformation was occurring and increasing during the dry season (no rain). We informed the City that we could not rule out the possibility that part of this section of Alum Rock Avenue road could fail catastrophically. The road was closed in August, 2000, because of public safety concerns. The development and enlargements of the cracks stopped almost immediately after road closure. During this same time period, similar distress did not occur in Highland Drive, Crothers Road, or the maintenance road.

### *Rainfall*

Rainfall is a well recognized causative factor of landsliding. We reviewed historic rainfall records from the nearby weather stations: Mt. Hamilton, San Jose, and the Penitencia Water Treatment Plant. The data for the Mt. Hamilton and San Jose stations were supplied by the U.S. Weather Service and consisted of daily rainfall totals between 1948 and 1999. The data for the Penitencia Water Treatment Plant was supplied by the Santa Clara Valley Water District, and consisted of daily rainfall totals between 1962 and 1999.

The yearly and daily rainfall amounts indicate that the winter of 1997-98 was wet, but not abnormally so. A large storm on Mt. Hamilton produced almost 4 inches of rain in February, 1998, but a similar amount did not fall on the Penitencia station or on the San Jose station during the same time.

What is notable about the rainfall at the Penitencia station (and therefore the study area) is that there was a relatively continuous series of storms during January and February, 1998. The January storms generated 4.65 inches of rain in this area spread throughout the month. A little more than 6.7 inches of rain fell in February, 1998, but over half of that amount (3.5 inches) fell during the first week of February, 1998. Similar patterns (with lesser amounts) occurred during the following winters. In 1998-99, almost 4 inches of rain fell in January, 1999, and 3.35 inches fell in February, 1999. In 1999-2000, more than 5 inches fell in both January and February, 2000. A similar pattern also occurred in 1983. During January, 6.5 inches of rain fell, in February, 5.2 inches of rain fell, and in March, 6 inches of rain fell.

The difference between January and February, 1998, and the other time periods was that the week of heavy rain in February, 1998, occurred after a month of relatively continuous rain. In all the other rainy periods, either the week of heavy rain occurred early in the season, or the individual heavy rain storms occurred as single events, spaced more than a week apart. This spacing of storms allowed surface and subsurface waters to drain out of the landslide between storms.

Irrigation watering by homeowners can significantly increase groundwater levels. We did not have access to the water usage rates for the homes in the vicinity of the landslide. The yards were being watered, but there was no obvious indication of significant overwatering.

### *Stream Flow*

The Santa Clara Valley Water District maintains a stream flow gauge on Penitencia Creek, a few hundred feet east of the junction of Penitencia Creek Road and Noble Avenue. They generously supplied copies of the Penitencia Creek stream flow data for use in this study. The headwaters of Penitencia creek are 7 to 9 miles east-southeast of the study area, and stream flows are more a function of rainfall in the Mt. Hamilton area as opposed to rainfall in the Alum Rock-Park area. The Cherry Flat Reservoir is located east of the Park on the upper reaches of Penitencia Creek. Prior to its construction in the 1930's, destructive flash floods would periodically flow through the park, destroying buildings and washing out roads. The other tributary, Arroyo Aguague, has no flood control structures on it.

The stream flow data indicates that there were high stream flow rates (up to 304 cubic feet per second [cfs]) in the last week of January, 1998. A peak flow rate of 304 cfs is high, but not unusual. However, peak flow rates during February, 1998, were low, varying between 8 and 36 cfs. This type of fluctuation is not unusual, and occurs every few years. For comparison, daily peak flow rates during the summer typically range between 4 and 8 cfs. The maximum recorded flow rate in the past 20 years was 446 cfs on March 1, 1983. A coarse conversion suggests that a flow rate of 10 cfs equates to about 1/2 a foot depth of water in the creek at the landslide. A flow rate of 300 to 400 cfs equates to 3 to 5 feet of water depth in the creek at the landslide.

### *Surface Runoff*

We observed the roads to examine water flow patterns and evaluate if road water runoff could flow onto the landslide complex. Crothers Road, the Maintenance Road, and Highland Drive slope from east to west, while Alum Rock Avenue slopes from west-to-east. All could potentially direct additional surface waters onto the landslide complex.

There is a surface drain on the Maintenance Road that directs road runoff away from the landslide. That drain is approximately 200 feet east of the eastern boundary of the landslide complex, but it is only 50 feet east of the eastern boundary of the watershed in which the landslide is located. Descriptions of pre-landslide surface runoff patterns along the Maintenance Road by Park personnel (Mr. T. Capurso) indicated that there was a continuous east-to-west slope of the Maintenance Road. Across the landslide, surface runoff on the Maintenance Road flowed over the landslide and was directed into a surface drain near Alum Rock Avenue. The lack of surface gullying on the slope adjacent to the downhill side of the Maintenance Road suggests that there was no historic pattern of water diversion from the road surface.

A surface drain on Crothers Road is located just west of the junction between Crothers Road and Miradero Avenue, about 700 feet east of the eastern boundary of the landslide complex. Observations of flow patterns on this section of Crothers Road indicate that water flows west towards the landslide. Figure 16 (taken fall 1983) shows that there was a continuous east-to-west slope of Crothers Road where it passed over the landslide, and there was an asphalt berm along the outside edge of the road (Figure 14, location S). We did not observe surface gullying on the slope adjacent to the downhill side of this entire length of Crothers Road that would suggest

historic patterns of water diversion from Crothers Road. Surface runoff on Crothers Road flowed across the landslide, west to Alum Rock Avenue where it was directed into a piping system that drains directly into Penitencia Creek (Figure 14, location T).

Alum Rock Avenue slopes from west-to-east, beginning at the entrance to the Park at the top of the hill. There is a surface drain on Alum Rock Avenue at the east end of the landslide that gathers and directs road runoff onto the landslide (Figure 14, location U). The presence of this drain means that the runoff from an additional 150 to 200 linear feet of road surface was directed onto the landslide. This section of Alum Rock Avenue is within the natural watershed of this area, and no out-of-watershed runoff was diverted into this area. It should be noted that the presence of Crothers Road and the Maintenance Road redirected surface runoff from approximately 350 linear feet of road away from the landslide.

## Conclusions

The Crothers Road Landslide Complex is a large landslide complex that has been active for thousands of years. Movement rates are controlled by long-term rainfall patterns. During periods of drought, the landslide will temporarily cease movement. During wet periods (El Nino events) movement rates will increase. The landslide moved in 1983, 1998, 1999, 2000 and probably in 1987. This pattern corresponds to the wet and dry weather patterns over the past 20 years. The rainfall patterns over the past 100 years could be used to estimate increased periods of landslide movement. The relative lack of large trees within the landslide complex (when compared to the tree density on either side of the complex) also attests to the long-term, episodic nature of movement. Future movement rates will vary, but the landslide complex will continue to move for the foreseeable future. Under extended rainfall events, movement could be considerable.

In our opinion, the primary cause of the 1998 landslide movement was an extended period of rainfall during January, 1998, coupled with intense rain storms in early February, 1998. It was both the pattern and amount of rainfall that formed the triggering factor. The area experienced almost a month of rain during January, 1998. This increased soil moisture levels and provided time for water to seep deep into the landslide. During this time, the landslide began to creep. This movement caused noticeable distress to the Goode property and prompted Mr. Goode to file a damage claim with his insurance company in early February. In late January, there were relatively high water flows (304 cfs) in the Penitencia Creek at the toe of the slide. This flow (and depth) was sufficient to erode the landslide toe.

In early February, 1998, there was a week of heavy rain (3.5 inches). This caused the small failure on Crothers Road, east of the landslide complex, and accelerated movement of the landslide complex itself. By mid-February, the landslide had been creeping for several weeks. This generated sufficient displacement to cause the clays in the basal failure planes to weaken (the soil particles realigned and reduced the overall strength of the soil from peak to residual). Once this occurred, landslide movement rapidly increased, and large-scale failure soon followed (circa February 14, 1998).

Weather records show that similar rainfall events occurred in 2000, 1999, 1987, 1983, and probably many times before that. They caused the landslide to creep, but did not cause large-scale failure. It appears that the rainfall events during those time periods were sufficiently spread apart that groundwater was able to drain from the landslide mass between storms. This reduced

groundwater buildup, which in turn, reduced overall landslide displacement and did not cause large-scale, rapid failure to occur. It is likely that large-scale failure could have occurred during any of these other time periods had there been slight changes in rainfall patterns.

A secondary cause of the failure was erosion of the toe of the landslide by Penitencia Creek. Periodic toe erosion prevented the landslide from achieving long-term self-stabilization. Whenever the landslide moved, it would shift to a just barely stable configuration (factor of safety equal to  $\approx 1.0$ ). The creek would then erode the toe of the landslide, reduce the stability of the landslide, and make it more conducive to failure. Creek flows are controlled by rainfall 5 to 10 miles away from the landslide and are not necessarily related to rainfall rates in the landslide area. High creek flows can occur during low rainfall in the landslide area, and vice versa. This means that there is not necessarily a direct time correlation between toe erosion and landslide movement. The toe could be severely eroded in the late spring of one winter which would not affect landslide movement until the next winter or later.

We do not think landslide movement was related to man-made features (roads, pipelines, houses, etc.). There has been virtually no change in those features for the past 50 to 70 years. If surface runoff from the development of the Highlands subdivision, Crothers Road, Alum Rock Avenue or the maintenance road (or water leaks from the Highland Drive water main) were a significant causative factor, the landslide would have moved within a few years after those features were constructed. It is likely that there was seepage from the sewer lines beneath Crothers Road and Highland Drive. Given the size of the landslide, the volume of water that could have leaked from those pipes would have been too small to have had any effect on the timing or scale of landslide movement.

The only change that we are aware of during the past 20 years was the construction of a water main along Crothers Road circa 1979. We do not think that there is a relationship between this water main and landslide failure. If this pipe developed a small leak, the volume of flow and pressure in the pipe would rapidly create a large leak that would quickly come to the ground surface. The history of distress to this main indicates that it was damaged as a result of the landslide pulling the pipe apart, not failing prior to earth movement.

There is no genetic relationship between the development of the slip out (Figure 14, location E) and the overall landslide complex. They were both caused by the extended period of rain in early 1998, but formation of the slip out did not cause or contribute to the development of the Crothers Road Landslide Complex.

In our opinion, the conceptual road repair method for Alum Rock Avenue proposed by Kleinfelder (A frame tie back retaining wall) is reasonable and is technically feasible. This assumes that the landslide is a classic translation feature with no deep movement. Kleinfelder's analysis is contingent upon three critical factors: depth to groundwater, soil properties, and depth to the basal slide plane. They noted that groundwater levels within the landslide mass must be kept 20 feet or more below the ground surface in any repair method. This would require construction of deep subdrains throughout the landslide mass as well as periodic maintenance and repairs for the life of the wall. Construction of the subdrains would require extensive excavations throughout the upper part of the landslide. Because the landslide mass would still be able to move, the subdrains would have to be designed to withstand several feet of movement. This would require periodic inspections to evaluate their condition and possibly repair/replacement of some of the subdrain lines.

Kleinfelder's analysis was based on minimal site specific soil properties. This is acceptable for this type of preliminary analysis but would not be acceptable for a design. If a retaining structure were to be built, extensive drilling and geotechnical testing program to better quantify soil/rock properties and subsurface conditions would be necessary. The depth to the primary basal slide plane was based on limited borehole and inclinometer data, and was assumed to be located approximately at the contact between fresh and weathered rock (50 to 55 feet below the ground surface). A small volume of subsequent inclinometer readings suggests that some movement is occurring about 75 feet below the ground surface at inclinometers I-4 and I-5. If the assumed value for any of these factors is inadequate, then the size and cost of the wall could be larger.

Kleinfelder's cost estimate for the repair of Alum Rock Avenue was based upon the width of the landslide shown on Figure 39. Our mapping indicates that the landslide is possibly 125 feet wider than Kleinfelder's estimate. If the width of the landslide or the depth of the active failure surface is deeper than assumed (75 feet vs. 55 feet), these could have major cost and scale impacts on any repair scheme. Identification of the extent and depths of active failure surfaces is critical to a complete understanding of the landslide complex.

It appears that the distress to Alum Rock Avenue that occurred during the summer of 2000 was primarily related to the volume of vehicular traffic that was using the road. Road deformation stopped almost immediately after public vehicle traffic was stopped. The soil supporting the road was deformed by landslide movement, and it appears that the weight and vibrations from the number of cars and trucks using the road were actively deforming the road. It is likely that similar deformation would recur if the road were reopened to a high volume of traffic.

## **CLOSURE**

This report was prepared at the request of, and for the exclusive use of, the City of San Jose and the San Jose Water Company. Norfleet Consultants is an independent consultant who was retained to provide an impartial evaluation of the Crothers Road Landslide Complex. The scope-of-work of this study and report were to provide a probable cause-of-damage evaluation of the study area to a reasonable degree of geologic/engineering certainty. This report is not intended to serve as a design level engineering report.

The opinions and recommendations presented in this report are based on reconnaissance level observations of the surface conditions of the area, and evaluation of information contained in reports provided to us by the client. All reported dimensions and sizes are approximate. Subsurface exploration, destructive testing, and other types of specialized investigations were not performed. It is possible we have not reviewed all reports concerning this area, and that conditions may exist, which were not identified or evaluated due to the limited scope-of-work of this evaluation. The opinions and/or recommendations presented in this report could be subject to revision should additional information become available.

We have employed generally accepted civil engineering and engineering geology procedures. Our observations, professional opinions and conclusions were made using that degree of care and skill ordinarily exercised, under similar conditions, by civil engineers and engineering geologists practicing in this area as of the date of this report.

Yours truly,

NORFLEET CONSULTANTS

Sands H. Figuers  
Principal Geological Engineer

RG-4749	exp. 10/31/02
CEG-1850	exp. 10/31/02
RGp-954	exp. 10/31/02
CHG-500	exp. 10/31/02
C-51495	exp. 6/30/02

## Crothers Road Landslide Complex

Table 1: Horizontal and vertical displacement of some of the survey points installed by Santa Clara County between 4/98 and 2/00. Units are in feet. See Figure 44 for point locations.

<u>PT. #</u>	<u>VERT. ELEV MOVEMENT</u>	<u>HORIZONTAL MOVEMENT</u>	<u>PT. #</u>	<u>VERT. ELEV MOVEMENT</u>	<u>HORIZONTAL MOVEMENT</u>
1	0.00	0.00	35	0.06	0.05
2	0.00	0.01	36	0.13	0.05
3	0.02 +	0.02	37	0.02 +	0.08
4	0.02	0.01	38	0.00	0.01
5	0.08	0.05	39	0.02	0.10
6	0.14	0.18	40	1.43	2.20
8	0.11 +	0.64	43	0.05 +	
10	0.06 +	0.63	47	0.10	0.19
11	0.12	0.92	48	0.07	0.11
14	0.06	0.03	50	0.02	0.00
15	0.01	0.01	52	0.00	0.00
18	0.06	0.05	53	1.81	2.81
19	0.02	0.07			
20	0.02	0.06			
21	0.01	0.02			
22	0.02	0.01			
23	0.01 +	0.03			
24	0.07 +	0.00			
25	0.07 +	0.00			
27	1.19	0.58			
28	1.45	1.40			
32	0.22	0.06			
34	0.07	0.04			



## Crothers Road Landslide Complex

### References

- Earth Tech, 1999, Phase I Geotechnical investigation - evaluation for emergency protective measures Crothers Road area landslide Santa Clara County, California; unpublished report for the County of San Jose, Roads and Airports Department, report dated January 20, 1999, project number 32652.10.100, 72pp.
- Kleinfelder, 2000, Stability analysis at Alum Rock Avenue entrance, San Jose, California; unpublished report for the City of San Jose, dated September 6, 2000, project number 44000276, 27pp
- Nilsen T. H., 1972, Preliminary photointerpretation map of landslide and other surficial deposits of the Mount Hamilton quadrangle and parts of the Mount Boardman and San Jose Quadrangles, Alameda and Santa Clara Counties, California; USGS MF-339
- Nilsen T. H., 1975, Preliminary photointerpretation map of landslide and other surficial deposits of the Calaveras Reservoir quadrangle, Alameda and Santa Clara Counties, California; USGS OFR 75-277-10
- Nilsen, T. H., Taylor, F. A., and Dean R. M., 1976, Natural conditions that control landsliding in the San Francisco Bay Region-an analysis based on data from the 1968-69 and 1972-73 rainy seasons; USGS bulletin 1424, 35 pp
- Nilsen, T. H., Wright, R. H., Vlastic, T. C., Spangle, W.E., 1979, Relative slope stability and land-use planning in the San Francisco Bay Region, California; USGS Prof. paper 944, 96pp.
- Merrill, M. J., 1983, Preliminary geotechnical inspection Leonard Residence 16219 Highland Drive San Jose, California; unpublished report for Farmers Insurance Company, Merrill and Seeley project 41183, dated December 28, 1983, 10pp.
- Radbruch, D. H. and Wentworth, C. M., 1971, Estimated relative abundance of landslide in the San Francisco Bay region, California; USGS open file report 71-231
- Wright, R. H. and Nilsen, T. H., 1974, Isopleth map of landslide deposits, southern San Francisco Bay region, California, USGS MF-550